System-Level Synthesis of MEMS via Genetic Programming and Bond Graphs

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Abstract. Initial results have been achieved for automatic synthesis of MEMS system-level lumped parameter models using genetic programming and bond graphs. This paper first discusses the necessity of narrowing the problem of MEMS synthesis into a certain specific application domain, e.g., RF MEM devices. Then the paper briefly introduces the flow of a structured MEMS design process and points out that system-level lumped-parameter model synthesis is the first step of the MEMS synthesis process. Bond graphs can be used to represent a system-level model of a MEM system. As an example, building blocks of RF MEM devices are selected carefully and their bond graph representations are obtained. After a proper and realizable function set to operate on that category of building blocks is defined, genetic programming can evolve both the topologies and parameters of corresponding RF MEM devices to meet predefined design specifications. Adaptive fitness definition is used to better direct the search process of genetic programming. Experimental results demonstrate the feasibility of the approach as a first step of an automated MEMS synthesis process. Some methods to extend the approach are also discussed.

1 Introduction

Mechanical systems are known to be much more difficult to address with either systematic design or clean separation of design and fabrication. Composed of parts involving multiple energy domains, lacking a small set of primitive building blocks such as the NOR and NAND gates in used VLSI, and lacking a clear separation of form and function, mechanical systems are so diverse in their design and manufacturing procedures that they present more challenges to a systematic approach and have basically defied an automated synthesis attempt.

Despite the numerous difficulties presented in automated synthesis of macro-mechanical systems, MEMS holds the promise of being amenable to structured automated design due to its similarities with VLSI, provided that the synthesis is carried out in a properly constrained design domain.

Due to their multi-domain and intrinsically three-dimensional nature of MEMS, their design and analysis is very complicated and requires access to simulation tools

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with finite element analysis capability. Computation cost is typically very high. A common representation that encompasses multiple energy domains is thus needed for modeling of the whole system. We need a system-level model that reduces the number of degrees of freedom from the hundreds and thousands of degrees of freedom characterizing the meshed 3-D model to as few as possible. The bond graph, based on power flow, provides a unified model representation across multiple energy domain system and is also compatible with 3-D numerical simulation and experimental results in describing the macro behavior of the system, so long as suitable lumping of components can be done to obtain lumped-parameter models. It can be used to represent the behavior of a subsystem within one energy domain, or the interaction of multiple domains. Therefore, the first important step in our method of MEMS synthesis is to develop a strategy to automatically generate bond graph models to meet particular design specifications on system level behaviors.

For system-level design, hand calculation is still the most popular method in current design practice. This is for two reasons: 1) The MEMS systems we are considering, or designing are relatively simple in dynamic behavior -- especially the mechanical parts -- largely due to limitation in fabrication capability. 2) There is no powerful and widely accepted synthesis approach to automated design of multi-domain systems.

The BG/GP approach, which combines the capability of genetic programming to search in an open-ended design space and the merits of bond graphs for representing and modeling multi-domain systems elegantly and effectively, proves to be a promising method to do system-level synthesis of multi-domain dynamical systems [1][2]. In the first or higher level of system synthesis of MEMS, the BG/GP approach can help to obtain a high-level description of a system that assembles the system from a library of existing components in an automated manner to meet a predefined design specification. Then in the second or lower level, other numerical optimization approaches [3], as well as evolutionary computation, may be used to synthesize custom components from a functionality specification. It is worthwhile to point out that for the system designer, the goal of synthesis is not necessarily to design the optimum device, but to take advantage of rapid prototyping and "design reuse" through component libraries; while for the custom component designer, the goal may be maximum performance. These two goals may lead to different synthesis pathways. Figure 1 shows a typical structured MEMS synthesis procedure, and the BG/GP approach aims to solve the problem of system-level synthesis in an automated manner in the first level.

However, in trying to establish an automated synthesis approach for MEMS, we should take cautious steps. Due to the limitations of fabrication technology, there are many constraints in design of MEMS. Unlike in VLSI, which can draw on extensive sets of design rules and programs that automatically test for design-rule violations, the MEMS field lacks design verification tools at this time. This means that no design automation tools are available at this stage capable of designing and verifying any kind of geometrical shapes of MEMS devices. Thus, automated MEMS synthesis tools must solve sub-problems of MEMS design in particular application domains for which a small set of predefined and widely used basic electromechanical elements are available, to cover a moderately large functional design space.